Mathematical Modeling of Automatic Voltage Regulators and Power System Stabilizers for a Hydroelectric Generating Unit of CFE-México

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Abstract - On July 31, 2008, undamped power oscillations of low frequency were registered in the Mexican National Electric System in which the 600 MW Hydroelectric Generating Station “El Caracol” oscillates respect to the National network. The event was recorded by phasor measurement units making possible the identification of electromechanical mode unstable and the dominant modes of the oscillation. From the developed analysis, it was found an unstable electromechanical mode associated with the generating units of “El Caracol”.

In this paper, the performance tests of Excitation Systems and Power System Stabilizers of the “El Caracol” generating units are presented, and the developed analysis for mathematical modeling and validation of these control systems.

Keywords: mathematical modeling, excitation systems, power system stabilizers, automatic voltage restorers.

1 Introduction

Analysis of power systems and, operating and planning decisions are mainly based on the results of studies and simulations carried out by using mathematical models of electronic devices and electrical components in the electrical system. Therefore, it is of great interest, to model and to validate the components of the analyzed system properly in order to have confidence in the obtained results [1].

Damping problems in power systems are generally associated with the interaction of the control system of generating units, the power demand condition and the electrical network topology. In modern interconnected power systems, power system stabilizer (PSS) is widely utilized to damp low frequency power oscillations [2][3].

In this paper, the main interest is in the Automatic Voltage Regulators (AVR) of the generating units and in the PSS, which mathematical models representing properly their performance and, their corresponding validation by means of field testing and computer simulations constitute a fundamental part in determining the factors of greatest impact on the damping problem and its solution [2][4].

Difficulty in events reproduction and solution of the oscillations problems in power systems is the high level of modeling required for such studies, because the detail needed to represent each generator and its control systems, which requires considerable work in identification, mathematical modeling, validation and testing of control systems of the generating units. In most cases it is necessary to conduct field tests, which implies the need for highly trained human capital, test equipment and the availability of generating units.

In this paper the methodology for modeling and validation of a real AVR and PSS installed in the Hydroelectric Generating Unit (HGS) “El Caracol” of Federal Electricity Commission (CFE) is presented. This is a 600 MW generating station which is part of the Mexican National Electric Power System.

The particular interest in to obtain an appropriate representation of the AVR, and PSS that allows a detailed analysis exists due to “El Caracol” generating unit has contributed with the mayor participation in the undamped low frequency power oscillations, recorded on July 31, 2008, in the Mexican National Electric Power System. The focus for the solution of the oscillations problem was directed toward adjust of the PSS of this generating unit.
2 Methodology for the mathematical modeling of the AVR and PSS.

In order to obtain a model for the AVR and PSS control devices of the mentioned generating unit, the next procedure is carried out:

1) To check the AVR, PSS and generators parameters.
2) To verify in field, data of manufacturer and adjust of the control system.
3) To test the performance of the AVR and PSS.
4) To develop and to validate the mathematical models.
5) To constitute a data base about the dynamic performance.

For constituting a data base describing properly the dynamic performance of the power system, it is important to represent each of the sources of damping in the system, such as excitation systems, PSS, and speed governor. Thus, the load characteristics that will make the model truly represents the system can be found.

It is important to mention that, under the coordination of the Operation Management of the National Energy Control Centre (CENACE) of CFE, a group of engineers was conformed to analyze and to solve the undamped oscillations of power recorded on July 31, 2008. The analysis group was formed by CFE specialist of the sub-management of CENACE, the Specialized Engineering Unit, sub-management of Programming, Generation and, Transmission and, The Equipment and Materials Test Laboratory.

3 Performance test of the excitation systems and Power System Stabilizers

The main objective of testing the control systems of the HGS “El Caracol” is to verify and to validate the electrical parameters of their excitation systems and PSS through controlled testing by applying voltage steps, and steps of positive and reactive power, with and without the PSS [5][6].

The parameters of the excitation system to verify are the time constant of the transducer (TR), the gain in transitory state and, time constants of the advance-delay networks.

The parameters of the power system stabilizer to verify are the gain of power loop and, constants of delay time.

3.1 No-load test for dynamic regime

No-load tests are carried out to evaluate the performance of the excitation control system with typical test signal (voltage step) and verified that the characteristic response parameters meet the correspondent CFE norm in [4].

The characteristic parameters are response time, overpass time, stabilization time, damping constant, overpass and, maximum and minimum limits excitation.

Tests are developed by modifying the AVR reference to such a value that varies the generator voltage by 5%, 10% and 20% of its rated voltage.

3.2 Load Test for dynamic regime

Load test are carried out to evaluate the performance of the excitation control system with typical test signal (voltage step) and verified that the characteristic response parameters meet the correspondent CFE norm in [7].

Load test are carried out to evaluate the damped characteristics and the response time of excitation control system when there are sudden changes of reactive power in the system [7].

Tests are developed by modifying the AVR reference to such a value that varies the generator voltage, which is equivalent to an increase of 1% of MVAr the reactive power.

4 Development of mathematical models for Control Systems and PSS

Because studies to solve the power oscillations of low frequency registered on July 31, 2008, will be developed in the DSATools digital simulator [8], mathematical models of control systems and PSS for the HGS “El Caracol” are required in the format of this simulator.

4.1 Excitation system

Block diagram of AVR provided by the manufacturer of the HGS “El Caracol” is shown in Fig. 1. The HGS consist on three generating units which have the same type of AVR.

The DSATools power system simulator has an available library of standard IEEE models for control systems, however, as can be observed in the block diagram of Fig. 1, this excitation system does not correspond to standard model. Therefore, is necessary to build an “user-defined model”, this is a particular model to adequately represent the dynamic behavior of the excitation system.

Fig. 1 Block diagram of the excitation system for the HGS “El Caracol”
In AVR scheme is observed a proportional-integral (PI) type controller with variable limits (see Fig. 1). To develop the mathematical model using DSATools it is necessary to create a block of dynamic limits and making an artifice to represent the proportional action of the controller.

A series of analysis were carried out with the information provided by the manufacturer (block diagram and description of variables, short circuit and saturation curves, firing angles of the thyristors converter, etc.), for calculating the parameters values of the mathematical model describing the dynamic behavior of AVR [2].

Fig. 2 shows the block diagram in DSATools format of the mathematical model developed for studies of AVR in the time domain. Fig. 3 shows the detail block of the integrator with variable limits.

The diagram shown in Fig. 4 does not correspond to a standard model. Therefore, it is necessary to build a "user-defined model" to adequately represent the dynamic behavior of the PSS.

Fig. 4 Block diagram of the Power System Stabilizer

Fig. 5 shows the block diagram in DSATools format of the mathematical model developed for studies of the PSS in the time domain.

5 Validation of mathematical models

With the developed mathematical models of AVR and PSS, a dynamic database was created, and digital simulations were conducted of the tests of voltage steps at no-load and, reactive steps, with two settings of the phase shift angle of the signal of stabilization (0 and 0.25 p.u., equivalent to 0° and 22.5°, according to the model of the PSS) [6].

Fig. 5 Mathematical model of the PSS for “El Caracol” generating units, in DSATools format.

4.2 Power System Stabilizer

The block diagram of the PSS provided by the manufacturer of the HGU “El Caracol” is shown in Fig. 4. The PSS model is the same for all three units.
The mathematical model validation is carried out by comparing computer simulations with the results of performance tests. Since the AVR and PSS for the three ‘El Caracol’ generating units are equal, in this paper only comparative results of one unit are shown, the HGU-U2 unit.

Before the testing of voltage steps at no-load, it shall be handed the machine at nominal voltage and values of field current and field voltage must be monitored, since these data will be considered as basic values referred to rotor, and will be required to standardize the signals of field voltage and field current from the numerical simulation, which will be compared with developed tests.

5.1 Tests of voltage step at no-load

This test consists of increasing in 10% the specified generator terminal voltage for the HGU-U2 (from 0.9 p.u. to 1 p.u.), when the generator is rotating at synchronous speed and is disconnected of the power system. For digital simulation, conditions of the test were considered and a voltage step of 10% was applied in the reference signal of the mathematical model. Fig 6 shows the HGU-U2 voltage at terminals obtained from the test and, the results obtained by means of digital simulation.

It can be seen from Fig. 6 that results obtained by means of digital simulation are very close to those obtained from the applied test. Then, it can be concluded that the mathematical model adequately reproduced the performance of the excitation system.

For digital reproduction of the test, it was considered an increase at terminal voltage of 0.0381 p.u., which is equivalent to an increase of 42 MVAr in reactive power.

In Fig. 7-Fig 11 results of active power, reactive power, voltage at terminals, field voltage and, field current are comparatively shown.

5.2 Tests of reactive step without PSS

For this test the generator must be connected to the power system and voltage regulator in automatic mode, with the PSS disabled.
PSS has no effect for this test, as this is developed with the PSS disabled. From the graphs in Fig. 7-Fig 11 is observed good approximation of the monitored signals; therefore, it is considered that the mathematical model of the AVR reproduces successfully its dynamic performance.

### 5.3 Tests of reactive step with PSS and 0° phase shift angle

In this test, the generator must be connected to the power system and voltage regulator in automatic mode with the PSS enabled. It has been considered a 0° phase shift angle setting of the PSS stabilization signal and 1.2002 p.u. gain of this signal.

The AVR and PSS settings used for the simulation were obtained from manufacturers information, which were verified in the field.

In the digital simulation for reproduction of the test, it was considered an increase in the voltage at terminals of 0.0381 p.u., which is equivalent to an increase of 42 MVAr in reactive power. In Fig. 12-Fig. 16 are comparatively shown active power, reactive power, voltage at terminals, field voltage and, field current.

From the graphs in Fig. 12-Fig 16 it can be observed a good approximation in magnitude and phase of the shown signals, thus the mathematical model of the PSS is validated; it is observed that developed model satisfactorily reproduce the dynamic performance of the PSS.
6 Conclusions

In this paper the methodology for the mathematical modeling and validation of AVR and PSS for real generating units has been presented. Mathematical models of AVR and PSS developed in the DSATools simulator permit to analyze the dynamic performance of these devices with an acceptable accuracy.

It is critical to have all the information provided by the manufacturer, of the generators and their controls, otherwise, it must develop field tests to estimate parameters of generators and their control systems controls for the identification and validation of math models to be successful.

It is crucial to have highly qualified human capital to develop the identification, mathematical modeling, performance tests and validation of mathematical models to ensure success in solving problems of low frequency oscillations.

7 References


Biographies

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